Rational Use of Computed Tomography for Individual Health Assessment in Asymptomatic Population: Chinese Experience

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Introduction

Since computed tomography (CT) was invented and used clinically or in research, it is currently widely used in the diagnosis, staging, assessment of disease response to treatment, with clearer image quality and shorter scanning time. There are many diseases which are not easily found at an early stage with noticeable symptoms, unknowingly spread the infection to others and are easily missed. When clinical symptoms appear, the disease may have been on late stage, its therapeutic efficacy and prognosis will be significantly worse. CT can be used for screening of asymptomatic population and individual health assessment (IHA), improving the detection rate of diseases, achieving early diagnosis and early treatment of diseases, thus improving the survival rate of patients. Radiation production is inevitable during CT scans, despite protective measures are improving continuously. Among the radiation doses of which the examinees received, the proportion of CT examination as a source of radiation is increasing. How to use CT rationally for IHA in asymptomatic population and to reduce the radiation dose of CT has become a research hotspot. In 2014, WHO held an international summit on "the reasonable application of CT in the IHA of asymptomatic population" in Munich, Germany, and reached a consensus. At present, the European and American countries have more studies on the usage of CT for IHA in an asymptomatic population with lung cancer, colorectal cancer, and coronary heart disease and have established a relevant strategy. This paper summarizes and analyses the utilization of CT and associated radiation-dose reduction in asymptomatic population in China.

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Feasibility and Necessity of the Use of Computed Tomography for Individual Health Assessment in Asymptomatic Population in China

CT is currently developing very rapidly within the last decade. Up-to-dated technologies are emerging. The sophisticated CT which has been launched since 2008 is called as "after 64 row CT".[1] High-tech CT with its associated hardware and software are progressing. The problem of CT scanning dose has been one of the main factors restricting the development of CT and attracted wide attention. The effective methods to reduce CT radiation dose to patients includes the use of a prospective electrocardiogram (ECG) triggering of the scan, dual source CT (DSCT) and higher helical pitch, and "projection space denoising" technique.[2] Radiation dose has been significantly reduced. Currently, there are more than 10,000 CT scanners in hospitals in China. Rural community hospitals have one or more CT scanners. The capacity of having CT scanners is 8.6 per million populations.[3] The price of CT examination is relatively cheap in China, such as 15–32 € per plain CT head examination. The amount of CT examination is rising progressively. According to the United Nations Scientific Committee on the Effects of

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Atomic Radiation, the medical use radiation-dosage accounts for 98.2% of all man-made radiation dose, whereas among the medical diagnostic modalities, CT as a source of radiation has the highest proportion.[4] International Commission on Radiological Protection (ICRP) proposed that X-ray radiation dose of 1 mSv received will increase the incidence of malignant tumors of 5/100,000.[5] CT may cause higher collective medical radiation-dose received by examinees, while for same diagnostic tests in different hospitals, their radiation-dose received by patients is somewhat different. There are two reasons: (1) the equipment and technique parameter are different among hospitals, (2) there are no consensus guidelines for CT scanning parameters in China. CT technologists in some hospitals have no enough awareness of low-dose scanning. Clinically, asymptomatic population fails to show noticeable symptoms in the early stage of disease, and few of them receive treatment. Thus, the rational use of CT for IHA in an asymptomatic population is feasible and necessary in China.

Computed Tomography Radiation-dose Index

The common indicators of the CT radiation-dose measurement are volume CT dose index (CTDIvol), dose length product (DLP), and effective dose (ED). CT radiation dose was positively correlated with these three indices.[6] CTDIvol refers to the ratio of total radiation-dose absorbed by patient to X-ray beam width (mGy) during a CT examination. CTDIvol reflects the physical quantity of radiation-dose received by the subject. In general, the greater the CTDIvol, the more severe the biological effects caused by the radiation, and the more serious the damage to the body. DLP refers to CTDIvol × scan length. DLP is positively proportional to scan length, so that DLP implies the total radiation-dose received by patient during CT examination, and can be evaluated as random effects of radiation hazard index. ED = DLP × k (mSv), which does not refer to an ED but rather accumulative exposure to the risk of ionizing radiation, such as inducing cancer, can fully evaluate radiation to different tissues and organs, which unit is mSv.

Rational Use of Computed Tomography for Individual Health Assessment in Asymptomatic Population in China

The rational use of low-dose CT (LDCT) for IHA in the asymptomatic population may improve lesion-detection performance. In 1977, ICRP[7] proposed three principles of medical radiation protection including the legitimate practice, optimization of medical radiation protection, and limitation of an individual dose. Its main purpose is to optimize radiological diagnosis through the protection and implementation of quality assurance programs, so that good image quality can be obtained while radiation dose of patients can be reduced.[8] In 1990, after Naidich *et al*.[9] first proposed the concept of LDCT, while either CT manufacturers, physicists, or medical staff engaged in dose-radiation protection are doing the research constantly on LDCT scanning parameters settings and related technologies. The study of LDCT in foreign countries has started earlier, the research scope and the level of the research are more comprehensive and in-depth. The authors have sorted the relevant literature on the use of CT for IHA in an asymptomatic population in China and conducted the analysis and summary.

Chest

Based on the latest foreign guidelines of lung cancer screening, in 2015, a cardiothoracic group of Chinese Society of Radiology (CSR) launched the latest Chinese Experts' Consensus[10] on low-dose spiral CT for lung cancer screening in 2015. They recommended LDCT screening for lung cancer in the high-risk Chinese population of lung cancer, and suggested that the high risk patients are defined as: 50–75 years of age; and at least one of the following risk factors: (1) smoking ≥20 pack/year, including those with past smoking history, but <15 years of smoking cessation; (2) passive smokers; (3) occupational exposure history (asbestos, beryllium, uranium, radon, etc.); (4) with a history of malignancy or a family history of lung cancer; and (5) with chronic obstructive pulmonary disease or diffuse pulmonary fibrotic disease.

The LDCT scanning technology requirements including CT of above 16 rows for lung cancer screening is recommended. The scanning range is from the apex to the costophrenic angle level. For helical scanning mode, the pitch setting is ≤1, gantry rotation time is ≤1.0 s, scanning matrix set is not <512 × 512 (specific technical parameters are set based on different models), with large visual field (field of view = L); those with no iterative reconstruction technique can use the scanning parameters of 120 kV, 30–50 mAs, whereas those with new generation of iterative reconstruction technique can use 100–120 kV, <30 mAs as scanning parameters; if the reconstruction slice thickness is ≤0.625 mm, gapless reconstruction can be performed, if reconstruction slice thickness ranged from 0.625 to 1.25 mm, reconstruction interval should be ≤80% of slice thickness; reconstruction is performed by using standard algorithm, or pulmonary algorithm with standard algorithm. During the procedure, it is recommended to activate the "dose report" function, so that automatically generated dose report by the device will be stored for routine storage.

Lung cancer screening is still controversial worldwide. While assuring the important significance of screening for lung cancer for detection of early lesions and reduction of the mortality of lung cancer, it still has many problems which need to improve. The main problems include a choice of screening tools, screening team quality, appropriate screening object, and establishing a sound screening program and guidelines. Munich conference expert consensus: (1) IHA CT for lung cancer detection should not be provided to the people under 55 years of age; (2) IHA CT detection of lung cancer should not be provided to population with no smoking history, or daily smoking history of one pack but <20 years and no other risk factors; and (3) personal risk prediction model should be used to select those who have lung cancer risk. IHA CT can be provided to the asymptomatic population equivalent to 5% of the risk of lung cancer in 5 years. If the risk is low, IHA CT can also be provided, but the assessment of risks versus benefits is needed. Annual or biannual screening can be provided to the population of 55–74 years of age; (4) IHA CT should be provided by radiologists and physicians of respiratory medicine; (5) the relevant information and knowledge of risk and benefit of CT IHA should be explained in detail to nonprofessionals.

Currently, most IHA focus on the detection of early stage lung cancer and lung damage of asymptomatic smokers in China.[11] LDCT for lung IHA has a high sensitivity in early detection of asymptomatic lung cancer.[11] Patients only need to receive fewer radiation dose and similar images as produced by conventional dose can be obtained, thus the radiation dose can be minimized and diagnosis can be made. LDCT for IHA in asymptomatic population detects early-stage lung cancer more as compared to conventional X-ray examination.[12] Li *et al*.[13] compared radiation dose of lung LDCT and that of conventional-dose examination. The scanning parameters were tube voltage of 120 kV, tube current of 20 mAs, CTDIvol of 1.38 mGy (77.8% lower than the conventional dose), and DLP of 44 mGy/cm (75% lower than a conventional dose of 180 mGy/cm). LDCT is suitable for lung cancer IHA in asymptomatic high-risk population. Nie *et al*.[14] reported lung cancer detection rate of 2.3% by LDCT for IHA in an asymptomatic population. Sone *et al*.[15] reported lung cancer detection rate of 0.48% by LDCT for IHA in an asymptomatic population. Li *et al*.[16] used low-dose lung high-resolution CT (tube voltage 120 kV, tube current 40 mAs) to investigate the lung damage condition of asymptomatic smokers and nonsmokers, and found that the incidence of lung emphysema, air trapping, and pulmonary parenchyma micronodule were significantly increased in smokers than nonsmokers.

With the improvement of cardiac CT equipment and the emergence of new technology, radiation dose has fallen to 0.8–2.0 mSv.[17]

Munich expert consensus includes: (1) to diagnose coronary heart disease in asymptomatic population by CT, the procedure should be monitored and guided by cardiologist, (2) based on NICE guidelines, CG95, 2010, it is reasonable to provide CT coronary calcium score (CTCS) for those with a significant risk of coronary artery disease (>10%). Only asymptomatic individuals older than 45 years old can self-refer for radiologic examination, (3) since CT coronary angiography (CTCA) and CTCS have good prognostic value, assessment by reusing CTCA or CTCS should be after 5 years.

There is no relevant guideline in China, the indications for coronary CT angiography (CTA) as an IHA tool for asymptomatic people in China include men, the elderly over the age of 40, a family history of premature coronary heart disease, smoking (current smoking >10 cigarettes/day), high blood pressure, high cholesterol, severe obesity (overweigh *t* > 30%), and medical history of cerebral vascular or peripheral vascular occlusion. Among them, high blood pressure, high cholesterol, and smoking are considered to be the most important three coronary heart disease risk factors.

CTA is used as an important IHA tool for detecting coronary artery disease of asymptomatic people in China.[18] DSA is used as gold standard but is invasive and relatively high costs. How to find and evaluate this part of the high-risk asymptomatic population with vulnerable plaque have become a hot spot and the difficult point of this study. Li *et al*.[19] conducted an analysis on 292 cases of coronary angiography in asymptomatic patients and found that 112 cases (38.4%) had noncalcified plaques, 83 (28.4%) cases of level 1 luminal narrowing, 13 (4.5%) cases of level 2 narrowing, 10 (3.4%) cases of level 3 narrowing, and 6 (2.0%) cases of level 4 narrowing. Iwasaki *et al*.[20] found that of the 415 low-risk asymptomatic patients, 295 cases (71.1%) of which had different degrees of coronary atherosclerosis.

CTA can also be used to assess prognosis and treatment efficacy in an asymptomatic population. Wang *et al*.[21] analyzed the coronary CTA and observed the occurrence of coronary artery disease in the asymptomatic population (60 cases). In 28 cases of the myocardial bridge, the left anterior descending artery had the highest incidence. A total of 52 vessels plaque formation was found, left anterior descending coronary artery had the highest rate of occurrence, accounting for 51.9%, and the incidence of soft plaque and mixed plaque were 32 and 13, respectively. Mild to moderate luminal stenosis also most commonly occurred in the left anterior descending coronary artery. Currently, DSCT scanning technology adaptation sequence is considered to be the most effective method to reduce the radiation dose of coronary CTA. Lv *et al*.[22] used DSCT on 100 patients for low-dose coronary angiography (prospective sequence scanning technology), in addition to the fixed scanning parameters, the range of body mass index (BMI)[23] was mainly used as a reference to adjust the tube voltage, tube current, and contrast agent flow rate. For BMI >24 kg/m^2, the tube voltage was 120 kV, tube current 260 mA, contrast agent flow rate 5.5 ml/s; for 24 ≥ BMI ≥ 18 kg/m^2, the tube voltage was 100 kV, tube current 210 mA, contrast agent flow rate 5 ml/s; for BMI <8 kg/m^2, and the tube voltage was 100/80 kV, tube current 210 mA, contrast agent flow rate 4.5 ml/s. The CTDIvol produced by prospective low-dose CT scan with ECG gating technology was 11.96–14.25 mGy, which was about a quarter of the value in retrospective ECG gating (8.2 ± 0.1) mGy.

Head

Head CT scan is a noninvasive IHA tool for detecting intracranial lesions, skull lesions, and other head diseases of asymptomatic people in China. It may provide crucial information for the preventive care, early detection, and early treatment of disease to decrease morbidity and mortality. Wang and Tian[24] published head CT IHA of

21,358 asymptomatic people demonstrated asymptomatic cerebral infarction (ACI) prevalence was 3.84%, followed by sinusitis, encephalomalacia, intracranial tumors, and skull bone tumor. ACI is low before the age of 40. ACI starts to rise after the age of 40 years old and rises significantly after the age of 50. Head CT presents a clear display of the gray matter, the white matter, the ventricles, the sulci, and the cisterna. The attenuation differences in CT between the gray and the white matter is smaller, e.g., CT value of the gray matter is about 32–40 Hu, while CT value of the white matter is about 28–32 Hu. The attenuation difference in CT between cerebrospinal fluid (CSF) and the brain parenchyma is relatively larger as compared with the difference between the gray matter and the white matter. The ventricle, the sulci, and the cisterna are filled with different amounts of CSF. The above reasons and skull bone artifacts, especially in the skull artifacts, impose stringent requirements for quality control to reduce noise effects, and radiation protection. There are several reports of LDCT in adult and more reports in children in China. The lens and the thyroid are extremely sensitive to radiation. It is generally believed that radiation dose of 0.5–2.1 Gy to the eyeball can cause corneal opacity, and radiation of larger than 5 Gy causes cataracts.[25] Although radiation dose to the eyeball from a single head CT scan is far below the dose which cause corneal opacity or cataracts, the cumulative effect to the eyeball from multiple head CT scans should not be ignored. Therefore, choosing a suitable low-dose scanning protocol is crucial. Ding *et al*.[26] published a head CT study with low-dose CTA (tube voltage 80 kV, tube current 150 mAs) to investigate intracranial aneurysms (ICAs) as compared to the conventional dose group. Their effective radiation dose was reduced by 69.73%. There was no significant change in sensitivity, specificity, and accuracy for the detection of ICAs. Chen *et al*.[27] reduce the radiation dose by reducing the tube voltage, using tube voltage 70 kV and automatic tube current regulation technology in head CT angiography. Compared with conventional dose scanning (tube voltage 120 kV), the radiation dose was decreased by 80%, but intravascular CT value was increased by 76%. Despite the decrease in tube voltage, the intravascular CT value was increased, which might be due to iodine absorption spectrum characteristics. The indications for low-dose head CT as a IHA tool for asymptomatic people in China include: 40–49 years old with high blood pressure, diabetes, smoking, alcoholism, family history of stroke, and intracranial arterial stenosis; over 50 years old people can have routine head CT scan to find intracranial lesions; people <40 years old are not recommended to undergo CT to avoid ionizing radiation.

Abdomen and pelvis

Early neoplasms of abdominal and pelvic internal organs such as the liver, gallbladder, spleen, pancreas, kidneys, gastrointestinal (GI) tract, bladder, uterus, and accessory organs are mostly asymptomatic. A lot of symptomatic neoplasm patients who go to see a doctor are on late-stage. The difference in density between abdominal and pelvic tissues and organs is not substantial. The difference in tissue contrast between abdominal and pelvic tissues and organs is not obvious, for example, on a plain CT a renal tumor has a slight low density, and the difference in density between renal tumor and normal kidney is not obvious unless contrast-enhanced CT is applied. To obtain high image quality, the high tube current is usually used in conventional abdominal and pelvic CT, which leads to a high radiation dose to the patient. Simply reducing tube current reduce radiation leads to an increase in image noise, thus conventional low-dose abdominal and pelvic CT obtained certain restrictions.[28]

Abdomen and pelvis: Colorectum

Current international and domestic studies on the low-dose of abdominal CT mainly focus on the screening of colorectal cancer. The 2014 Munich, Germany conference has formed an expert consensus.[29] Supporting the routine follow-up of the utilization of CT colonography (CTC) in asymptomatic high risks population for colorectal cancer (e.g., a family history of rectal cancer or colonic polypoid disease, based on relevant guidelines. CTC[30] for IHA of the asymptomatic patient should only be performed in patients at age 45 and above, if the risk of colorectal cancer in individuals younger than 45 years old increased, screening should be done according to published guidelines. For individual with negative findings on CTC or with asymptomatic polyp of <6 mm in diameter by CTC, CTC should not be re-performed within 5 years.

The air and feces within the colorectum often provide natural contrast; reduction in radiation dose can ensure adequate image quality. Radiation dose to a patient is directly proportional to the tube current while other parameters are fixed. Liang *et al*.[31] published a colorectal cancer IHA with low-dose CT (tube current 50 mAs) after inflating colorectum to obtained satisfactory images. Their sensitivity, specificity, and accuracy were 96.5%, 62.5%, and 89.2%, respectively. The indications for LDCT as a colorectal cancer IHA for asymptomatic people in China[32] include positive immunoassay fecal occult blood test; first-degree relatives with colorectal cancer; history of cancer; or history of intestinal polyps.

Abdomen and pelvis: Liver

Currently, there are a few studies using low-dose liver CT for IHA in asymptomatic people in China. Xu *et al*.[33] used iDOSE enhanced CT iterative reconstruction technique to obtain high-quality images at lower dose levels to assess liver tumors. Their ED was reduced by 49.71% as compared to conventional dose. The iterative reconstruction technique selectively removed noise, made it possible to obtain high-quality images at lower dose levels. Wang *et al*.[34] evaluated low-dose liver CT perfusion under different circumstances of tube current. The study demonstrated that ED associated with low-dose (50 mA) CT perfusion imaging was 7.01 mSv, which was two-thirds of conventional dose, and obtained a more satisfactory image quality. The indications for low-dose liver CT as an IHA tool in asymptomatic people for high-risk liver cancer in

China include HBsAg (+), HBeAg (+), and HBcAb (+) or HBsAg (+), HBeAb (+), and HBcAb (+), with AFP more than 2 times of normal value.

Abdomen and pelvis: Pancreas

Hu *et al*.[35] published a pancreas study with low-dose GE LightSpeed volume 64 slices CT to obtain high-quality imaging at lower radiation dose. Radiation dose to the pancreas increased along with increased waist circumference. The minimum current can be controlled within 60–80 mA, 70–90 mA, and 90–100 mA for waist circumference <90 cm, 90–110 cm, and >110 cm, respectively. In the allowed milliampere range to change, LDCT underwent in accordance to the corresponding waist-circumference optimized protocol. The image quality met the diagnostic requirement.

Abdomen and pelvis: Gastric cancer

Gastric cancer is one of the most common GI malignancies in China with the high prevalence of occult primary. Nearly, half of patients with early gastric cancer have no obvious symptoms. Early IHA in asymptomatic patients has important clinical value. The major clinically diagnostic methods in patients suspected of harboring gastric cancer include barium meal and GI endoscopy, but both have some limitations. These methods may not display tumor invasion and extension to the surrounding tissue, distant metastasis, and lymph node metastasis. LDCT has added value in the evaluation of detection, tumor, node and metastasis staging, and prognosis of gastric cancer. Kumano *et al*.[36] employed LDCT in the diagnosis of early gastric cancer with detection rate (88.2%). The indications for low-dose liver CT as an IHA tool in asymptomatic people for high-risk gastric cancer in China[37] include family history of GI cancer; bad eating habits: irregular eating pattern, high salt/hot food, carcinogenic substances with high nitrite content of preserved, smoked food, etc.; chronic alcoholism or smoking; long-term mental health disorders; particular occupation: long-term exposure to dust clouds of sulfuric acid, lead, asbestos, herbicides, and metal industry workers; geology, water containing harmful substances.

Abdomen and pelvis: Kidney

The incidence of renal cell cancer (RCC) ranked second among all the urinary tract cancers. The 50% of asymptomatic kidney cancer is early detected by physical examination. Mo *et al.*[38] published an RCC IHA with CT (tube voltage 120 kV, tube current 100 mAs) and obtained satisfactory perfusion images. Their effective radiation dose was 8.95 mSv. The indications for low-dose kidney CT as an IHA tool for asymptomatic people in China[39] include age > 40 years, smoking, engaged in manufacturing oil, leather, asbestos, and family history of RCC.

LDCT has superior sensitivity and accuracy for detecting urinary calculi. The calculus and calculus-induced hydronephrosis form a high contrast with the surrounding soft tissue. Reduction in tube current over a certain range is litter effect on the detection rate of urinary calculi. Zhu *et al*.[40] used 120 kV, 50 mAs for low-dose scanning and obtained high-quality images, which is able to accurately locate the stone.

Abdomen and pelvis: Bladder

The indications for LDCT as bladder cancer IHA tool for asymptomatic people in China[41] include a family history of bladder cancer, smoker, and contact with carcinogenic chemicals. Chen *et al*.[42] published a study with low-dose bladder CT (tube voltage 120 kV, tube current 40 mAs) after inflating bladder and obtained satisfactory images to detect urinary lesions as compared to conventional dose CT (tube current 120 mAs).

Nasopharynx and ear

Globally, 80% of patients with nasopharyngeal carcinoma (NPC) are in China. Early NPC is mostly asymptomatic but can be detected by IHA with LDCT in China. Early detection of NPC has a great impact on the prognosis. Thereby increasing the efficiency of NPC IHA in asymptomatic people to improve early detection of NPC, has a significantly clinically value. The lenses, which are sensitive to radiation, are unfortunately inevitable within the field of nasopharyngeal skull base scanning. Chen *et al*.[43] published a study with low-dose skull base CT (a decrease in tube current from 200 mAs to 70 mAs). Their ocular radiation was reduced (from 145.38 mGy to 50.34 mGy, equivalent to a third of the former). Their image quality was not significantly sacrificed, while using 50 mA may impact the diagnosis due to poor image quality. A protocol (120 kV, 70 mA) is considered to be more suitable for LDCT nasopharyngeal skull base scan. Shen *et al*.[44] used LDCT (120 kV, 50 mA) on pharyngeal to clearly show tumor extension into parapharyngeal space and surrounding metastatic lymph nodes. The indications for LDCT as an NPC IHA tool for asymptomatic people in China include live in the Southern provinces of China; aged 30–59 years; a family history of NPC; regular contact with cooking oil fumes, carcinogenic chemicals; and tobacco and alcohol use. High-risk population: IgA/VGA antibody titers ≥ 1: 80; have any two of three positive indicators of IgA/VGA, IgA/EA, and Dase.

Yuan *et al*.[45] conducted a preliminary study on the usage of 64 slice CT for low-dose CT scanning of the temporal bone, when the mA value of the temporal bone scanning decreased from 380 to 160 mA, CTDIvol fell from (47.8 + 2.7) mGy to (20.1 + 2.0) mGy, without affecting the premise for the diagnosis, the radiation dose of the patient was only 42% of the original dose, achieving the expected goal of meeting the requirements of the diagnosis and reducing the radiation dose.

Bones

Currently, LDCT for IHA of asymptomatic people in bones and skeletal system mainly focus on the sacroiliac (SI) joint, lumbar spine. The natural contrast between SI joint and it surrounding soft tissue is good on LDCT. Ankylosing spondylitis (AS) mainly affects joints in the spine and the SI joint of young men. SI joint CT is associated with radiation exposure to the reproductive organs. Reduction in dose from SI joint CT is very important to patients, particularly reproductive-aged patients and patients who require long-term multiple follow-up SI joint CT scan evaluation in patients with AS. Yang[46] published an AS IHA with low-dose SI joint CT (tube voltage 130 kV, tube current 60 mAs) to obtain high-quality images to detect AS in comparison with conventional dose CT (130 kV, 260 mAs) and demonstrated no significant difference between LDCT and conventional dose CT in the diagnosis and classification of AS. Ding *et al*.[47] published an AS IHA with low-dose 64-slices helical SI joint CT (care dose four-dimensional technology, tube voltage 120 kV, and tube current 61–94 mAs) to obtain high-quality images in the detect AS in comparison with conventional dose CT (220 mAs). The mean CTDIvol was 68.8% lower with the low-dose protocol. The indications for SI joint CT as an IHA tool for asymptomatic AS people in China include <40 years old male; family history of AS.

LDCT can be used for IHA of asymptomatic people with lumbar disc herniation, scoliosis, and kyphotic deformities. LDCT provide a detail view of the anatomical relationship of the spinal cord, roots, intervertebral disks, vertebrae, and soft tissues supporting spinal column. Zheng *et al*.[48] used iterative reconstruction technique to reduce radiation dose to obtain high-quality imaging in 256-slice lumbar spine CT. The patients were randomized into one of the four groups based on the following scan protocol 120 kV/automatically adjusted tube current (mean value was 237 mAs), 120 kV/150 mAs, 80 kV/300 mAs, and 80 kV/150 mAs, respectively. The corresponding CTDIvol were 15.74 mGy, 10.1 mGy, 5.86 mGy, and 2.92 mGy, respectively. They demonstrated CT scan protocols of 120 kV/150 mAs, 80 kV/300 mAs CT scan protocol reduce radiation does while providing good image quality.

Xiang *et al*.[49] used LDCT in the detection of pelvic lesions of men and women in childbearing age. The mean CTDIvol was 78% lower with the low-dose protocol of 120 kV, 50 mA as compared with conventional dose (120 kV, 210 mA). The image quality obtained by tube current 50 mA had no difference as compared with conventional dose (210 mA). Low-dose pelvic CT (tube current 50 mA) in men and women of childbearing age provides reduce radiation does while providing good image quality.

Strategies for Radiation-dose Optimization for Low-dose Computed Tomography

Currently, there are several of LDCT for IHA of asymptomatic people in China. It is an interesting hot topic regarding how to achieve necessary diagnostic quality with the least amount of radiation dose. It is crucial to find the optimal balance the relationship between radiation-dose and diagnostic quality. China employs the following strategies for radiation-dose optimization in CT for IHA of asymptomatic people.

Reduce tube voltage on computed tomography

Tube voltage determines X-ray penetrability. Radiation dose is directly proportional to the square of tube voltage, while noise is inversely proportional to the tube voltage. The increase in tube voltage increases the amount of radiation dose, for example, when voltage is increased from 120 to 140 kV, the radiation-dose increases by 30–40%. When tube voltage is decreased, radiation dose and X-ray beam quality will both decreases, which cause large changes in tissue contrast and increase image noise. For the issue with very little natural contrast, reducing tube voltage does not affect intrinsic contrast between tissues but significantly decrease radiation-dose.[50] Schindera *et al*.[51] employed different tube voltages and adjusted iodine amount in contrast-enhanced abdominal CT and demonstrated the degree of contrast enhancement with tube voltages of 80 kV or 100 kV, respectively, is significantly higher in comparison with a tube voltage of 120 kV. The mechanism is that reducing tube voltage increases the photoelectric effect and decreases Compton scatter effect at the same time. A study from Strauss and Goske[52] showed tube voltage is decreased from 140 kV to 120 kV, radiation-dose decreases by 40%, and tube voltage is decreased from 120 kV to 80 kV, radiation dose decreases by 65%. For overweight people, lowing the X-ray tube voltage reduces the energy of the X-ray photon, decreases the inadequate penetration ability, decreases the X-ray received by detectors, increases the X-ray quantum noise in a CT image, and results in reduced image quality.

Reduce tube current on computed tomography

Tube current is directly proportional to radiation dose. The higher the tube current, the lower the radiation dose, otherwise, the lower the tube current, the higher the radiation dose. Thus, reducing tube current decreases radiation dose to patients, which is one practical means of reducing CT radiation dose. If tube current is reduced by 50%, radiation dose will be reduced by 50% of the original dose correspondingly.[53] Reducing tube current mainly affects low-contrast resolution, also known as low-density resolution or contrast detection capability, which is the ability to different two lesions with a minor density difference and is a key factor affecting CT image quality. When there is no substantial difference in attenuation coefficient between the lesion and surrounding normal tissue on CT, the poor low-contrast resolution will not be able to distinguish the lesion with a minor density difference from surrounding normal tissue. A decrease in tube current increases imaging noise and severely affects low-contrast tissue or organ such as the liver. The imaging noise severely causes blurred subtle tissue structure such as the blood vessels and bile ducts or lesions and reduces imaging quality, whereas there is little effect on high-contrast tissue or organ such as the lung. In recent years, an automatic tube current modulation (ATCM) technology, analogous to the automatic expose control, has been the most comprehensive method to reduce radiation dose in clinical practice. ATCM has been shown to decrease radiation dose by 18–26%.[54] ATCM customizes tube current delivery to subject's size, shape, and tissue density and enables automatic modulate tube current in the x-y plane (angular modulation), along the z-axis (longitudinal modulation). Almost all modern multidetector (MDCT) scanners are currently equipped with ATCM. This technology has become a very effective way in the radiation-dose management. ATCM is an effective means of reducing radiation dose while maintaining image quality.

Increasing the pitch on computed tomography

The pitch is the ratio of the table movement per 360° gantry rotation to the collimator width. The parameters such as pitch, collimation width, and table speed are related in a spiral scan process and affect the imaging quality outcome and radiation dose to the patients by varying degrees. Increasing pitch, while reducing scanning time, has the advantage of less imaging artifact. Slice sensitivity profile decreases as the pitch increases,[55] while reducing longitudinal spatial resolution, decreases soft-tissue contrast, has an adverse effect on image quality. Therefore, under the condition of little effect on diagnostic accuracy, high pitch should be used, whenever possible, however, should never impair the resolution of fine structures. In recent years, the newly adapted LDCT technology called adaptive statistical iterative reconstruction (ASIR) is increasingly used. ASIR[56,57] has proven a considerable development potential for improving image quality and reducing radiation-dose in CT relative to currently used filtered back-projection (FBP). The greatest strength of ASIR is its ability to improve image signal-to-noise ratio as compared to FBP, particularly in the case of the relatively poor raw dataset.

Current Application Status of Computed Tomography for Individual Health Assessment of Asymptomatic People in China

CT for IHA of asymptomatic people is being performed in China. This creates a number of challenges for Chinese government over how best to regulate specific indications for CT in IHA of asymptomatic people.[58] CT for IHA of asymptomatic people is strictly monitored and controlled to make sure they use the least amount of radiation possible while maintaining sufficient imaging quality to meet clinical need. It would be allowed from a legal point of view in China. CT examinations for IHA of asymptomatic people only reimbursed by employers in China. Guidelines for the use of CT for IHA of asymptomatic people should be established in China. Multidisciplinary research efforts are profoundly changing our understanding of the use of CT for IHA of asymptomatic people in China, the Chinese government has issued a series of laws and regulations concerning radiation safety under statutory authority. Adequate use-specific safety training program is repeated annually for each practitioner and employee engaged in radiation to increase awareness of the safety. All practitioner and employee engaged in CT must hold a radiation user license to ensure the safety of protection under statutory authority. Any use of CT for IHA in asymptomatic people is clearly documented (time, doses, and indications) and strictly followed by the physician and technologist. Standard operating procedures/protocol for CT should be instituted and monitored to doctor/technologist preference. Indication-specific protocols must be judiciously optimized by tailoring CT parameter and employing the latest technology to minimize radiation-dose based on patient size and pathology and to answer specific clinical concerns of each individual patient. Chinese's journey in LDCT research field has a 10 years' history. Most clinical trials with LDCT techniques have focused on the lungs and the heart. Advances in CT technology using dual-energy CT or MDCT provide an optimal balance between sufficient diagnostic image quality and lowest possible dose, which is a hot topic in CT research. There have been a number of LDCT studies of the head and neck including temporal bone, paranasal sinuses, and thyroid, the abdomen and pelvis including GI, GU, as well as the bone and joint. Under the passionate advocates and unwavering commitment to radiation-reduction of the leaderships of CSR of Chinese Medical Association and Chinese Journal of Radiology, in-depth and comprehensive LDCT research has been increasing exponentially conducted in China since 2007.[59] Research teams participating in the studies consists of an interdisciplinary team with radiologists, technologists, nurses, physicists, and radiation protection specialists. A variety of technology and strategies have been developed to use appropriate reduction in dose with sufficient quality of imaging for CT in the IHA of asymptomatic people. Currently, there are still no guideline and uniform protocol recommendations to LDCT critical parameters. There are still three controversial aspects regarding the use of LDCT in IHA of asymptomatic people,[60] which are economic feasibility, radiation safety issue, universal and potential clinical application. All the controversies will be solved to be found in the future.

In summary, CT for IHA of asymptomatic people is being performed in China. CT for IHA of asymptomatic people is strictly monitored. Indication-specific protocols are optimized by tailoring CT parameter and employing the latest technology to use the least amount of radiation possible while maintaining sufficient imaging quality to meet clinical need.

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Conflicts of interest

There are no conflicts of interest.

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